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(54) A COMPOSITE DIELECTRIC RESONATOR

(71) We, NIPPON HOSO KYOKAI of 2—3, 2-Chome, Uchisaiwai-Cho, Chiyoda-Ku, Tokyo, Japan, a corporation organised according to the laws of Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:

The present invention relates to a composite type dielectric resonator used in high frequency and more especially in millimeter wave range for which a stringent requirement for the stability of characteristics against temperature variation is imposed.

For the miniaturization of broadcasting equipment by introducing integrated circuit elements in quasi-millimeter wave range and for obtaining a high "Q" value in filters, a small dielectric resonator made of an integrated circuit element applied with dielectric material by vaporization has been proposed. However, a practical dielectric resonator has not been realized mainly due to the temperature charactistics. The resonant frequency of such dielectric resonator shifts according to temperature variation and thus a practical device can hardly be obtained.

M. R. Stiglitz had proposed a solution in "Frequency Stability in Dielectric Resonator" IEEE MTT-14 No. 9 September, 1966, page 311.

In the Stiglitz dielectric resonator, a dielectric resonator element is supported on an inner surface of a wave guide with an interposition of a high frequency insulator having high thermal conductivity, such as boron nitride BN, so that the heat loss caused by high frequency power and produced in the dielectric element of the resonator, such as titanium oxide TiO_2, is dissipated to the surface of the wave guide.

By applying the above teaching in a dielectric resonator, the temperature characteristic of the resonant frequency can be improved as seen in Fig. 1, in which a curve I shows the temperature characteristic of the above Stiglitz dielectric resonator and a curve II shows that of an ordinary resonator without applying the high frequency insulator. In such Stiglitz dielectric resonator, however, it is impossible to eliminate an influence of the ambient temperature.

Another proposal is described in an article written by M. A. Gerdine entitled "A Frequency Stabilized Microwave Band Rejection Filter Using Dielectric Resonators" IEEE MTT-17 No. 7, July, 1969. Fig. 2 shows an embodiment of a dielectric resonator of this type, which comprises two dielectric elements, for example, disks of TiO_2 1 and 3 oppositely arranged with an interposition of an air layer 5. The TiO_2 disks 1 and 3 are supported respectively by rods 7 and 9 which are made of insulating material having high coefficient of thermal expansion and of low dielectric constant. These insulating rods 7 and 9 are fastened to the side walls 11 and 13 of a waveguide by means of clamps 15 and 17, respectively., In this embodiment, the interval between the dielectric elements 1 and 3 is varied by changing the length of each of the supporting insulators 7 and 9 and the consequential change of capacitance acts, so as to compensate possible variation of resonant frequency characteristics owing to change of temperature of the dielectric elements. This principle can be applicable in designing a band rejection filter so as to stabilise the frequency of the filter against temperature variation. However, this principle is not suitable for a band-pass filter, and has a drawback in that the frequency is easily varied by mechanical oscillation. Furthermore, it is difficult to create a fine adjustment mechanism for the resonant frequency while maintaining the resonant frequency compensation characteristics against temperature.

An object of the present invention is to provide an improved form of dielectric resonator suitable for use in quasi-millimeter wave range and having a stabilised frequency characteristic at varying ambient temperature.

According to the present invention there is provided a composite dielectric resonator, comprising first and second dielectric elements, the sign of the temperature coefficient

of the relative dielectric constant of said first element being opposite to that of said second element, said dielectric elements being combined to contact each other at respective surface portions to form said composite resonator, the dimensions of said elements being chosen to provide in said composite resonator a stabilised resonant frequency over a wide range of temperature variation of said resonator.

Described another way, the materials forming the two dielectric elements should be chosen in the following relationship. Assuming the tensor dielectric constants for the two dielectric elements are

$$\overleftrightarrow{\varepsilon_1} \text{ and } \overleftrightarrow{\varepsilon_2}$$

respectively, then the temperature coefficients of the constants; i.e.

$$\frac{\partial \overleftrightarrow{\varepsilon_1}}{\partial t} \text{ and } \frac{\partial \overleftrightarrow{\varepsilon_2}}{\partial t}$$

are in the following relationship:

$$\int_{\tau_1} E^* \cdot \frac{\partial \overleftrightarrow{\varepsilon_1}}{\partial t} E d\tau_1 = -\int_{\tau_2} E^* \cdot \frac{\partial \overleftrightarrow{\varepsilon_2}}{\partial t} E d\tau_2 \quad (1)$$

wherein τ_1 and τ_2 designate the dimensions of each dielectric region (i.e. volume) and E designates the vector component of the high frequency electric field.

For a better understanding of the invention, reference is made to the accompanying drawings, in which:

Fig. 1 is a graph showing variation of resonant frequency owing to variation of temperature for two dielectric resonators;

Fig. 2 is a schematic cross-sectional view of a dielectric resonator of a known type proposed by Gerdine;

Fig. 3-a is a perspective view of a rectangular parallelepiped shaped dielectric resonator;

Figs. 3-b and 3-c are the explanatory diagrams for the basic oscillation mode in the resonator shown in Fig. 3-a;

Fig. 4-a is a perspective view of a disk shaped dielectric resonator;

Figs. 4-b and 4-c are diagrams showing the basic oscillation mode in the resonator shown in Fig. 4-a;

Fig. 5-a is a perspective view of a cylindrical shaped dielectric resonator;

Figs. 5-b and 5-c are diagrams showing the basic oscillation mode in the resonator shown in Fig. 5-a;

Fig. 6-a is a perspective view of an embodiment of a composite dielectric resonator made in accordance with the present invention;

Fig. 6-b is a perspective view of a different composite dielectric resonator according to the present invention;

Fig. 7 is a perspective view of a further composite dielectric resonator according to the present invention;

Fig. 8 is also a perspective view of another composite dielectric resonator according to the present invention;

Figs. 9 and 11 are graphs showing temperature-relative dielectric constant characteristics of certain dielectric materials used in resonators;

Fig. 10 is a diagram illustrating the contact surface between the two dielectric elements;

Figs. 12-a and 12-b are explanatory diagrams for a composite dielectric resonator according to the present invention;

Fig. 13 is a cross-sectional view of a dielectric resonator made in accordance with the present invention and showing a fine adjustment mechanism for compensating resonant frequency variation with temperature change;

Fig. 14 is an explanatory diagram showing another method of achieving the fine adjustment;

Fig. 15 is a cross-sectional view of a practical composite dielectric resonator made in accordance with the present invention;

Fig. 16 is an equivalent electric circuit diagram of the resonator shown in Fig. 15;

Fig. 17 is a graph showing temperature adjustment characteristics of the resonator of Fig. 15;

Fig. 18 is a graph showing a temperature-frequency characteristic of the resonator shown in Fig. 13 in comparison with that of a resonator of the conventional single type;

Fig. 19 is a temperature-frequency characteristic of the resonator shown in Fig. 15;

Fig. 20 is a cross-sectional view of a wave guide provided with a composite resonator according to the present invention;

Fig. 21 is a cross-sectional view of a band-pass filter using a composite dielectric resonator made in accordance with the present invention; and

Fig. 22 is a plan view of the band-pass filter shown in Fig. 21.

Before explaining full detail of the composite resonator according to the present invention, at first the basic oscillation modes in simple dielectric resonators of various forms will be explained, it being understood that to support such a wave mode the resonators require to be supported in a specific orientation in a wave-supporting structure.

There are three basic forms for the element of a dielectric resonator. These forms are a rectangular parallelepiped from (*a* and *b* >*c*), a disk form (L<D) and a cylindrical form (L>D), as shown in Figs. 3-a, 4-a and

5-a, respectively. The fundamental oscillation mode in the resonator shown in Fig. 3-a is the TE_{01} or dipole mode as shown schematically in Figs. 3-b and 3-c. The fundamental oscillation mode in the disk resonator shown in Fig. 4-a is the TE_{01} mode as shown in Figs. 4-b and 4-c in which the high frequency electric field E extends parallel to the disk surfaces. The fundamental oscillation mode in the cylindrical resonator shown in Fig. 5-a is the EH_{11} mode and the three sectional views of this EH_{11} mode are shown in Figs. 5-b, 5-c and 5-d. In this oscillation mode, the high frequency magnetic field H has magnetic dipole in a plane normal to the direction of the axis of the cylinder, and the high frequency electric field E extends substantially parallel to the direction of the axis.

Figs. 6-a and 6-b show schematically two basic forms of the dielectric resonator made in accordance with the present invention. The composite dielectric resonator shown in Fig. 6-a is made of two stacked dielectric plates 21 and 23. The dielectric constants, ε_1 of the plate 21 and ε_2 of the plate 23, are chosen to have temperature coefficients of opposite polarites. In order to give such characteristics, the two plates are made of, for example, TiO_2 and $LiNbO_3$, respectively. The composite dielectric resonator shown in Fig. 6-b is also made of two stacked dielectric plates 25 and 27 of which the dielectric constants ε_1 and ε_3 are chosen to have temperature coefficients of opposite polarities.

As was explained in the basic oscillation modes illustrated in Figs. 3-b, 3-c, 4-b and 4-c, an electric field E in the oscillation mode in the embodiments shown in Figs. 6-a and 6-b appear in parallel to the flat contact plane between the two elements in both the rectangular parallelepiped and disk shaped resonators. Examples of the characteristics of specific dielectric materials in this crystalline form are given in Figs. 9 and 11 by way of example, it being understood that the invention is not limited to the use of crystalline dielectric materials.

Fig. 9 shows a graph illustrating curves of relative dielectric constants $\varepsilon_{\perp}$ and $\varepsilon_{//}$ for single crystal of TiO_2 against temperature. In the graph the curve denoted $\varepsilon_{//}$ depicts the variation of relative dielectric constant with respect to temperature in a direction parallel to the optical axis of the dielectric material and $\varepsilon_{\perp}$ is that in a direction normal to the optical axis.

Fig. 11 shows a corresponding graph for the relative dielectric constants for single crystals of $LiNbO_3$. As shown in the drawings, the ε_1 and ε_2 have opposite sign in the temperature coefficient.

The disk resonator shown in Fig. 4-a can also be used in a composite dielectric resonator according to the present invention in a form shown in Fig. 7 where a circular hole is bored at the center of a dielectric disk, 32 having its relative dielectric constant ε_2 the hole housing an inner disk 31 having its relative dielectric constant ε_1 which has temperature coefficient of opposite sign with ε_2. In this embodiment shown in Fig. 7, the electric field component becomes weaker at a location closer to the center of the disk 31, so that it is preferable to make the dielectric constant ε_1 of the inserted inner disk 31 larger than that of the dielectric constant ε_2 of the outer disk 32.

In the case where the cylindrical resonator shown in Fig. 5-a is to be utilized, the electric field E appears substantially parallel to the direction of the axis of the cylinder. Therefore, a composite dielectric resonator according to the invention can be made of a hollow cylinder 33 having the dielectric constant ε_2 and of an inserted dielectric rod 35 having the dielectric constant ε_1 as shown in Fig. 8. The rod 35 is inserted into the hollow part of said cylinder 33. The temperature coefficients of the two dielectric constants ε_2 and ε_1 are selected to be opposite in sign.

The use of the composite type resonator shown in Fig. 8 is limited to the basic oscillation mode, the EH_{11} mode, in which the electric field is extending substantially parallel to the axis of the cylinder.

When a higher oscillation mode HE_{11} is produced in addition to said fundamental mode, the electric field component of the higher oscillation mode HE_{11} lies substantially parallel to a phane normal to the direction of the axis, and an electric field vector of the higher mode has a radial component E which is directed in the radial direction of the cylinders 33 and 35. As a result, when the contact surface of the two dielectric elements lies in the direction of the axis as shown in the structure of Fig. 8, the electric vector near the contact surface extends normal to the contact surface as shown in Fig. 10. For such oscillation mode the embodiment as shown in Fig. 8 is not suitable because as the higher frequency electric field component E intersects normal to the contact surface, it would be necessary to make the contact surface of both dielectric elements optically registrable for a reason set forth below.

Assuming, for example, that an air layer 37 is formed as shown in Fig. 10 owing to possible loose mechanical contact between the dielectric elements 39 and 41, a strong electric field is applied onto the air layer. If we assume the relative dielectric constant of the dielectric element as ε_r, and the electric field in the element as E, the electric field strength in the air layer 37 is $\varepsilon_r E$. Thus, the electric energy density in the air layer 37 is ε_r times larger than that in the dielectric element. With an air layer 37 having thickness t_a the relation between the diameter D of the dielectric element and the thickness t_a of the air layer 37 in

order to restrict the variation of resonant frequency to $p.10^{-x}$ where p and x are constants can be expressed as follows:

$$t_a \fallingdotseq \frac{pD\times 10^{-x}}{\varepsilon_r} \qquad (2)$$

If the relative position between both the dielectric elements is varied in order to perform the desired frequency compensation for the temperature variation or by a reason of secular deviation, said thickness t_a of the air gap cannot always be a constant value so that a certain deviation in an amount of Δt_a occurs. In this situation, it is desired to make the frequency deviation caused by said deviation Δt_a smaller than an influence caused by temperature variation. In order finally, to limit the frequency variation in a desired amount $p\times 10^{-x}$ at a certain range of temperature variation, said deviation of the thickness $t_a+\Delta t_a$ must be maintained in an extent shown in the equation (2). In case of using TiO_2 having characteristics as shown in Fig. 9 as the dielectric element, the relative dielectric constant ε_r is about 70—100. The diameter D of the dielectric disk is to be made in an order of about 5 mm in the frequency band of quasi-millimeter wave. If the frequency deviation due to temperature variation is to be finally limited within an order of 10^{-4} (i.e. p=1 and x=4) by the dielectric compensation, the amount $t_a+\Delta t_a$ must satisfy $t+\Delta t_a \fallingdotseq 0.005\mu m$ which is derived from the above equation (2). The above explanation is concerned for the adjustment for frequency compensation against temperature, but this principle can also be applied to the adjustment of the resonant frequency itself. In this application, if a fine adjustment range of the frequency is desired to be within $p\times 10^{-x}$, the amount of $t_a+\Delta t_a$ must be limited to a value determined by said expression (2). Now, it should be noted that the thickness t_a of said air layer 37 in Fig. 10 must be less than 0.005 micron, in case of applying the structure of Fig. 8 to said HE_{11} mode. It is, however, nearly impossible to obtain such an air layer of 0.005 micron, which is an optical contact surface, in view of accuracy of machining.

In the oscillation mode of HE_{11} in the embodiment shown in Fig. 6-b, the electric field component E is always parallel to the contact surface between the two elements. Consequently, if the contact surface of said two dielectric elements is arranged as shown in Fig. 6-b to extend parallel to the direction of the electric field, then said thickness t_a of the air layer 37 may be increased ε_r times, i.e., up to an order of 0.5 micron. This means that the machining accuracy is allowed for 100 times less. Usually such accuracy can easily be satisfied.

Furthermore, in order to obtain better frequency compensation against temperature variation of the dielectric resonator, the dielectric disk is formed in such a way that an optic or crystal axis is included in a surface of the disk 25 or 27 shown in Fig. 6-b. Generally, such a dielectric element has different dielectric constants in different directions, i.e., a value $\varepsilon_{//}$ in the direction of the optical axis and a value $\varepsilon_{\perp}$ in the direction of the surface normal to said axis differ each other. In the case of TiO_2 and $LiNbO_3$, for example, they have such temperature characteristics as shown in Figs. 9 and 11, in which generally it applies that $\varepsilon_{\perp}>\varepsilon_{//}$.

Accordingly, in the case of using the HE_{11} oscillation mode, if the directions of the axes of both dielectric disks 43 and 45, which are made of $LiNbO_3$ and TiO_2, respectively, are parallel to one another as in Fig. 12-a, the electric field in the direction normal to the axes of the disks is mainly directed in the direction of $\varepsilon_{\perp}$ at in the direction normal to the optical axis. If both dielectric disks 43 and 45 are arranged as shown in Fig. 12-b in a manner that their axes cross normal to each other, the direction of the electric field near the contact surface is not always in the direction of the angle of intersection but is directed rather closer to a direction normal to the optical axis of the dielectric element having larger $\varepsilon_{\perp}$, or in other word it is directed rather closer to the axis of the element having smaller $\varepsilon_{\perp}$. Thus, the equivalent dielectric constant is nearly equal to $\varepsilon_{//}$ in the element made of dielectric material of smaller $\varepsilon_{\perp}$. As a result, the electric energy component in said element having smaller ε_1 decreases. For the reason mentioned above, the distribution of electric energy in both dielectric disks 43 and 45 can be varied by changing the intersecting angle formed by the two axes of both dielectric disks, so that it is possible to make frequency compensation against temperature variation by adjusting said angle between the two axes so as to satisfy said equation (1). In this case, however, it follows that the resonant frequency is forced to vary by the above adjustment, therefore, it is necessary separately to provide a means for adjusting finely the resonant frequency. For example, in the arrangement, which is shown in Fig. 13, dielectric disks 47 and 49 are mounted on an earth plate 51 by a supporting bed 53 of insulating material having a small dielectric constant, at the center of which bed 53 a cavity 55 is provided. A member 56 for varying the resonant frequency, such as a screw of metal or dielectric substance is adjustably fitted so as to finely tune the resonant frequency by varying the length of a portion of said screw 56 which enters into said cavity 55.

Fig. 14 shows another arrangement in which a composite dielectric resonator comprises a

TiO_2 disk 57, a $LiNbO_3$ disk 59 and a thin disk 61 made of either one of the dielectric materials TiO_2 and $LiNbO_3$, which third disk 61 is placed on the stacked disks 57 and 59. By rotating said disk 61 about the axis, the resonant frequency may be varied finely. In this embodiment, it is assumed that the optical axis of each disk 57, 59 and 61 lies in the plane normal to each axis of said disks. The direction of the electric field in the thin disk 61 depends mainly upon the electric field in the two thick disks 57 and 59. Since in the case of using HE_{11} mode, the direction of electric field in the section parallel to each axis of the disks 57 and 59 is hardly influenced by the direction of the axis of the thin disk 61, if the axis of the thin disk 61 is coincident with the axis of the thicker disk 59 thereunder, the equivalent dielectric constant of the thin disk 61 is nearly $\varepsilon_{\perp}$, whereas if the axis of said disk 61 is normal to the axis of said disk 59, the equivalent dielectric constant in said disk 61 is nearly equal to $\varepsilon_{//}$. As a result of this, if a dielectric material which satisfies the relation $\varepsilon_{\perp} > \varepsilon_{//}$ is used as a dielectric material of the thicker disk 59, then the resonant frequency takes a minimum value when the direction of the axis of the thinner disk 61 is coincident with that of the thicker disk 59, and the resonant frequency takes a maximum value when both the axes are normal to each other. That is to say, resonant frequency of the composite dielectric can be finely adjusted by rotating said thinner disk 61 about the axis.

As described above, variation of resonant frequency caused by variation of temperature can be cancelled by combining two different kinds of dielectric materials, the dielectric constants of which have opposite signs to one another, so that it is possible to provide a composite dielectric resonator having highly stabilized resonant frequency. Moreover, since the dielectric resonator is so arranged when in use that the high frequency electric field does not cross the air layer at the contact part of both dielectric elements, the resonant frequency is not shifted by the change of said air layer, even if a condition of said air layer may be changed by a lapse of time or by a mechanical oscillation. Furthermore, a remarkable effect is obtained in that frequency compensation against temperature and fine adjustment of frequency can easily be realized by varying relative locations of both the dielectric elements in the contact plane thereof.

In a practical form of the wave-supporting structure for the resonator made in accordance with the present invention, further fine adjustment mechanism is provided for adjusting compensation characteristics of frequency deviation due to temperature variation. The basic form of composite resonator as explained above has a contact surface between two basic dielectric elements. Outside of the resonator or more precisely outside of both other surfaces of the composite dielectric resonator, an oscillation mode is produced which is termed as an evanescent mode. In this evanescent mode region, if we consider, for instance, TE_{01} mode, the magnetic energy is much stronger than the electric energy of the oscillation mode.

An adjustable metal element is preferably provided in the evanescent mode region outside of the resonator to adjust the interval between the metal element and the resonator surface so that the magnetic energy in a dielectric element is adjusted to control its contribution rate for the resonant oscillation of the composite resonator and a fine adjustment of the frequency deviation due to temperature variation is obtained.

In the embodiment of Fig. 13 frequency deviation up to a few MHz in 10 GHz band at a temperature variation range of −20°C to +80°C can be compensated. However, by applying only the basic principle of said embodiment of the invention, it has been difficult to compensate the frequency deviation more finely, i.e., in order of less than 1 MHz.

Fig. 15 shows a more practical and preferred embodiment in which a strip line transmission path 71 is arranged between outer plates 73 and 75 with interposition of supports 77 and 79 made of insulating material having a low dielectric constant, such as Teflon (Registered Trade Mark). A composite dielectric resonator made in accordance with this invention, which comprises flat disk or rectangular parallelepiped shaped dielectric elements 81 and 83, is disposed beside the strip line 71 and is supported on a supporting bed 85 having a cavity 85a. Tapped holes 87 and 89 are bored in the plates 73 and 75 at positions opposite to said dielectric resonator comprising elements 81 and 83. Threaded metal posts 91 and 93 are screwed into said holes 87 and 89, respectively, so that the distance between each top surface of said posts 91 and 93 and respective dielectric elements 81 and 83 can be varied by moving said metal posts 91 and 93 in the directions illustrated by arrows in the drawing. It is to be noted that the thickness of the bottom of said cavity 85a formed by the support bed 85 should be sufficient for providing strength to support said dielectric elements 81 and 83, and also it must be arranged not to obstruct the screwing of said metal post 93.

Fig. 16 shows an equivalent electrical circuit of the embodiment shown in Fig. 15. An upper-side impedance Z_{a_1}, viewed from the dielectric element 81 having characteristic impedance Z_{o_1} for the upper side, i.e., air side, is inductive in case of TE_{01} oscillation mode. The inductive component of the impedance Z_{a_1} becomes lower as the post 91 is moved

closer to said dielectric element 81. Accordingly, the impedance Z_{s_1} viewed from said dielectric element 81 into the upper evanescent region assumes smaller value, and as the post 91 is moved closer to the dielectric element 81, the magnetic energy in said dielectric element 81 increases. Same effect is applied to the lower-side impedance Z_{s_2} viewed from the dielectric element 83 having characteristic impedance Z_{s_2} into lower-side, i.e., air side.

On the other hand, the strength E_ϕ of the electric field in the circumferential direction in the dielectric element is always in a particular relation with the strength H_z of the magnetic field in the axial direction in the dielectric element. Since the total energy in the dielectric resonator is constant and this energy is distributed to both magnetic and electric energies the electric field strength E_ϕ in the resonator decreases according to an increase of the magnetic field therein, therefore the electric field energy in said two dielectric elements concentrates inside of the dielectric element apart from the metal posts 91 and 93.

If the dielectric materials the respective relative dielectric constant of which increases or decreases in response to temperature rise, for example, if TiO_2 and $LiNbO_3$ are used as the material of the dielectric elements 81 and 83, respectively, the distribution of total energy to electric or magnetic form varies, i.e. the magnetic energy in the dielectric element 81, i.e., in TiO_2 relatively increases and the electric energy in the same dielectric element 81 relatively decreases and an opposite effect occurs in the element 83 when the metal post 91 is moved toward the dielectric element 81. This is equivalent to a case when we assume the density of the dielectric element 81 made of TiO_2 becomes lower.

As a result, the contribution to the resonant frequency by the dielectric element 81 decreases, and thus the frequency variation caused by the temperature rise of the resonator shifts toward lower frequency when the temperature increases. Namely, the temperature gradient of the resonant frequency is negative in this adjustment. Conversely, if the metal post 93 is moved toward the dielectric element 83, the magnetic energy in said element 83 tends to increase and the contribution of said element 83 to the resonant frequency decreases, so that when $LiNbO_3$ having relative dielectric constant which increases according to temperature rise, is used as the dielectric element 83, as in the case of this embodiment, frequency deviation due to temperature rise of the resonator shifts toward higher frequency when temperature increases. Thus, the temperature gradient of the resonant frequency is positive in this adjustment.

In summary, according to the adjustment whether the post 91 is moved toward the dielectric element 81 or the post 93 is moved toward the dielectric element 83, the temperature gradient of the resonant frequency of the composite dielectric resonator can be adjusted to be either negative or positive sense.

In order to maintain the resonant frequency to be constant under a certain temperature, the post 93 should be so adjusted to move away from the dielectric element 83 when the post 91 is moved toward the dielectric element 81 and *vice versa*. The former adjustment is effective to make the temperature gradient of resonant frequency negative and the latter adjustment is efficient to make the gradient positive.

Fig. 17 shows characteristic curves for various combinations of the distance between the respective post and the respective dielectric element, when the resonant frequency is adjusted to be constant. The distance h_1 between the dielectric element 81 and the post 91 and the distance h_2 between the dielectric element 83 and the post 93 are expressed by a ratio with a diameter $2a$ of said dielectric elements 81 and 83, i.e., in Fig. 17, the abscissa and the ordinate are scaled by value $h_1/2a$ and $h_2/2a$, respectively. This graph shows curves for a constant frequency for various combinations of these values. In this figure, parameter Xo shown at each curve is obtained by multiplying the propagation constant in free space by the radius a of the dielectric element. A locus *P* of zero temperature gradient at the resonant frequency is drawn by connecting the center points of the curves. The temperature gradient of the resonant frequency assumes negative value when the distance values $h_1/2a$ and $h_2/2a$ are located in a region above said locus *P* marked as "negative" and the gradient assumes positive value when both distance values are located in a region below said locus *P* marked as "positive".

Thus, as described above, the distance between the metal post and the dielectric element is so adjusted that the deviation of resonant frequency due to temperature variation owing to the variation of the temperature characteristics of the dielectric elements, can be compensated.

The experimental result of compensation according to the present invention is now compared with the case of a prior art dielectric resonator. The result is shown in Fig. 18. In this figure, a dotted curve I shows a temperature characteristic of a single type known dielectric resonator employing only TiO_2, whereas a solid curve II shows that of a composite dielectric resonator as shown in Fig. 13 according to this invention. Comparing these curves I and II, it is clearly distinguished that

shift of resonant frequency against temperature variation in the composite dielectric resonator is much less than that in the single dielectric resonator. Furthermore, it is found that when using the composite dielectric resonator shown in Fig. 15, shift of the resonant frequency is limited within 200 KHz in the temperature range of −20°C to +80°C at a frequency band of 10 GHz, by appropriately adjusting both of the metal posts 91 and 93, the curve of the temperature characteristic being illustrated in Fig. 19.

Fig. 20 shows an embodiment of applying this invention in a waveguide. In Fig. 20, a composite dielectric resonator is composed of two dielectric elements 101 and 103 having flat cylindrical or rectangular parallelepiped shape having the axis normal to the side surfaces (E surfaces) 105 and 107 of the waveguide. This resonator formed by two elements 101 and 103 is supported by the bottom surface (H surface) 109 of this waveguide 100 on a supporting base 111 made of ceramics as an insulating material having low relative dielectric constant. In positions where the axes of said dielectric elements 101 and 103 intersect with the side surfaces 105 and 107, metal posts 113 and 115 are adjustably arranged to change the distance between said dielectric elements 101 and 103 and said posts 113 and 115, respectively.

The above mentioned embodiments of the invention are directed to band rejection filters. On the other hand, in order to provide a band-pass filter by using a strip transmission line, a composite dielectric resonator according to this invention may be arranged in the manner as shown in Figs. 21 and 22. Referring now to Figs. 21 and 22, a composite dielectric resonator composed of two dielectric elements 121 and 123 is disposed in a coupling area between two strip lines 125 and 127, the end portions of which are short-circuited to ground, the arrangement being positioned between two plates 129 and 131 by means of a supporting bed 133 made of insulating material having low relative dielectric constant. Said supporting bed 133 is provided with a cavity 135 with a thin partition 137 between said dielectric element 123 and said cavity 135. The plates 129 and 131 are bored with screw holes 139 and 141, respectively, in parts where these plates 129 and 131 are opposed to said dielectric elements 121 and 123, respectively. Threaded metal posts 143 and 145 are screwed into said holes 139 and 141, respectively, so that these posts 143 and 145 are screwed into said plates 129 and 131 toward said dielectric elements 121 and 123.

In case of providing a band-pass type filter by using a waveguide, a composite dielectric resonator of the type shown in Fig. 20 is positioned within a cut-off waveguide, to which input and output circuits are coupled.

A fine adjustment of the temperature compensation of the resonant frequency can also be realized by varying the distance between the metal posts and the dielectric elements, and which provides very easy adjusting facility. When TE_{01} mode is applied to the composite dielectric resonator, an induced current on the plate flows in the circular direction of the metal post, so that there is no conductor loss due to the adjusting movement of the metal post. Accordingly, fine adjustment of the temperature compensation of resonant frequency can be realized without decreasing "Q" value.

From the foregoing it will be understood that certain embodiments of the present invention have the advantageous effect of being able to adjust the temperature gradient of the resonant frequency as well as resonant frequency itself. That is to say, it is possible to adjust temperature gradient to zero at a given frequency.

WHAT WE CLAIM IS:—

1. A composite dielectric resonator, comprising first and second dielectric elements, the sign of the temperature coefficient of the relative dielectric constant of said first element being opposite to that of said second element, said dielectric elements being combined to contact each other at respective surface portions to form said composite resonator, the dimensions of said elements being chosen to provide in said composite resonator a stabilised resonant frequency over a wide range of temperature variation of said resonator.

2. A composite dielectric resonator as claimed in any preceding claim, wherein the two dielectric elements are made of TiO_2 and $LiNbO_3$, respectively.

3. A composite dielectric resonator as claimed in either preceding claim, wherein the dielectric elements are made of stacked rectangular parallelepiped elements.

4. A composite dielectric resonator as claimed in either one of claims 1 and 2, wherein the dielectric elements are made of stacked flat disk elements.

5. A composite dielectric resonator as claimed in either one of claims 1 and 2, wherein the dielectric elements are made of two concentric disk plates.

6. A composite dielectric resonator as claimed in either one of claims 1 and 2, wherein the dielectric elements are made of two coaxial cylinder elements.

7. A composite dielectric resonator according to any preceding claim, in combination with a wave-supporting structure, wherein the resonator is secured to a support attached to a plate forming a part of an outer wall of a waveguide cavity, and a pair of metal rods are adjustably arranged to move in an axial direction towards and away from said plate and another plate opposite thereto in a man-

ner that the distances between the end surfaces of the metal rods and the resonator surfaces can be adjusted, the resonator being disposed with respect to the wave-supporting structure so as to operate with a wave mode which has an electric field component extending parallel to the contacting surface portions of the dielectric elements.

8. The combination as claimed in claim 7, wherein the two plates are parallel to each other, each having a said metal rod screwed therein allowing axial movement toward the resonator outer surfaces and a strip line transmission circuit is arranged between said two plates with an interposition of supporting elements made of low dielectric constant insulating material.

9. A composite dielectric resonator according to any one of claims 1 to 6 in combination with a wave-supporting structure, wherein the resonator is secured to a support attached to an earthed plate, a metal rod being arranged adjacent an outer surface of the resonator and being adjustably mounted to move towards and away from said outer surface.

10. A composite dielectric resonator according to claim 4, and substantially as hereinbefore described with reference to either Fig. 12*a* or Fig. 12*b* of the drawings.

11. A composite dielectric resonator according to claim 10, when modified as described with reference to and as illustrated in Fig. 14 of the drawings.

12. A composite dielectric resonator according to claim 9, and substantially as hereinbefore described with reference to Figs. 13 and 18 of the drawings.

13. The combination according to claim 7 and substantially as hereinbefore described with reference to Figs. 15, 16, 17 and 19 of the drawings.

14. A composite dielectric resonator according to claim 1 in combination with a wave-supporting structure and substantially as hereinbefore described with reference to Fig. 20 of the drawings.

15. A composite dielectric resonator according to claim 1 in combination with a wave-supporting structure and substantially as hereinbefore described with reference to Figs. 21 and 22 of the drawings.

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FIG. 1

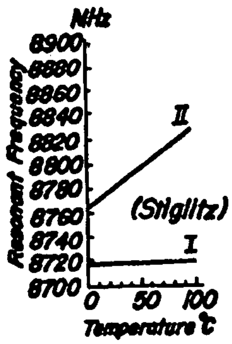

FIG. 2

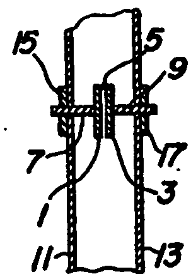

FIG. 3a

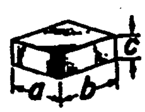

FIG. 3b

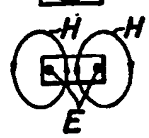

FIG. 3C

FIG. 4a

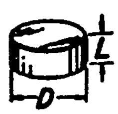

FIG. 4b

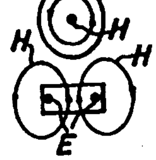

FIG. 4C

FIG.5a FIG.5b FIG.5c

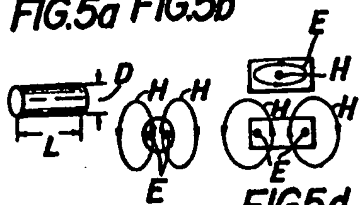

FIG.5d

FIG.6a

FIG.6b

FIG.7

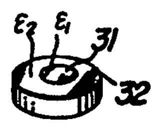

FIG.8

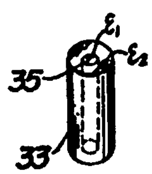

FIG.9

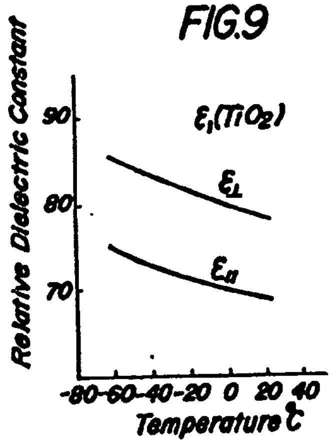

FIG.10

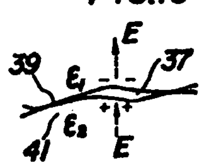

FIG.11

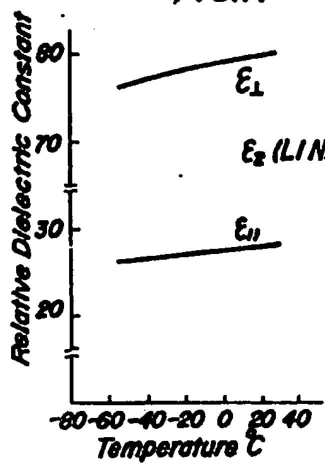

FIG.12a

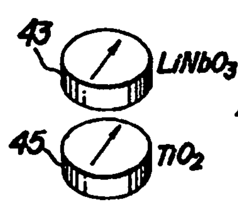

FIG.12b

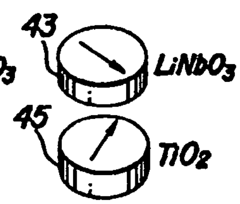

FIG.13

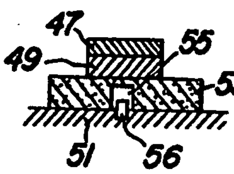

FIG.14

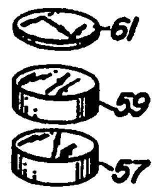

FIG.15

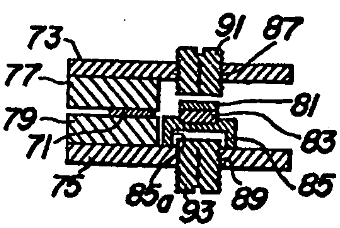

FIG.16

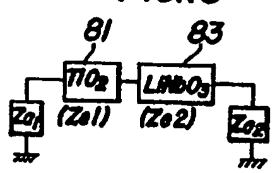

FIG.17

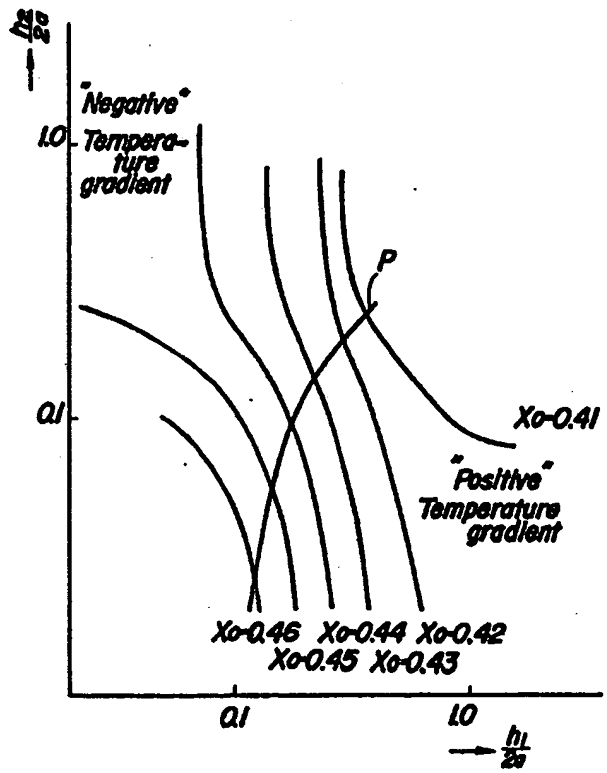
"Negative"
Tempera-
ture
gradient
1.0
0.1
P
Xo-0.41
"Positive"
Temperature
gradient
Xo-0.46
Xo-0.44
Xo-0.42
Xo-0.45
Xo-0.43
0.1
1.0

FIG.18

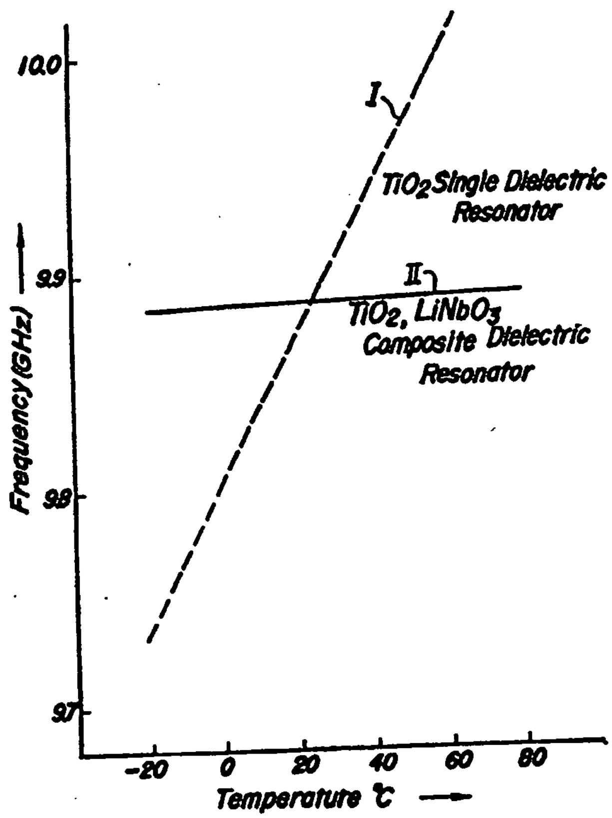
10.0
9.9
9.8
9.7
Frequency (GHz)
-20
0
20
40
60
80
Temperature ℃
I
TiO_2 Single Dielectric Resonator
II
TiO_2, $LiNbO_3$ Composite Dielectric Resonator

FIG.19

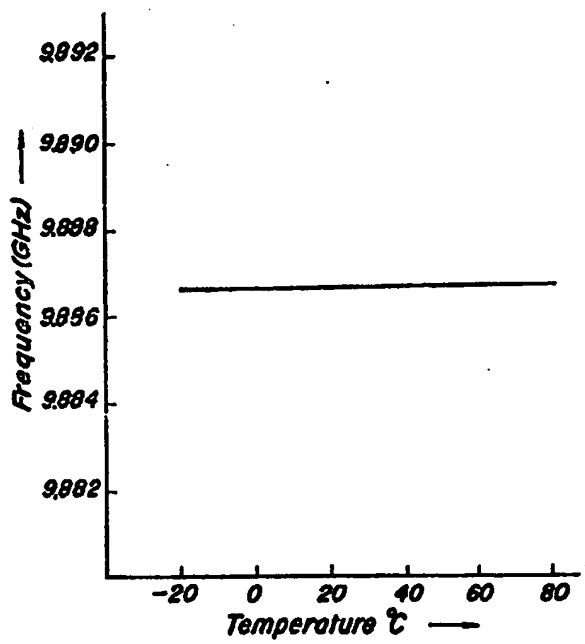
9.892
9.890
9.888
9.886
9.884
9.882
Frequency (GHz)
-20
0
20
40
60
80
Temperature °C

FIG.20

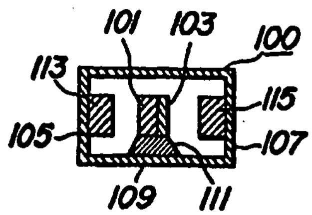

FIG.21

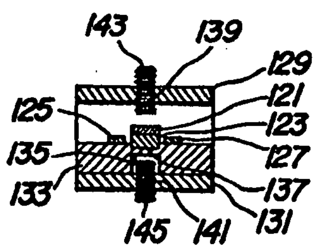

FIG.22